The Nineties

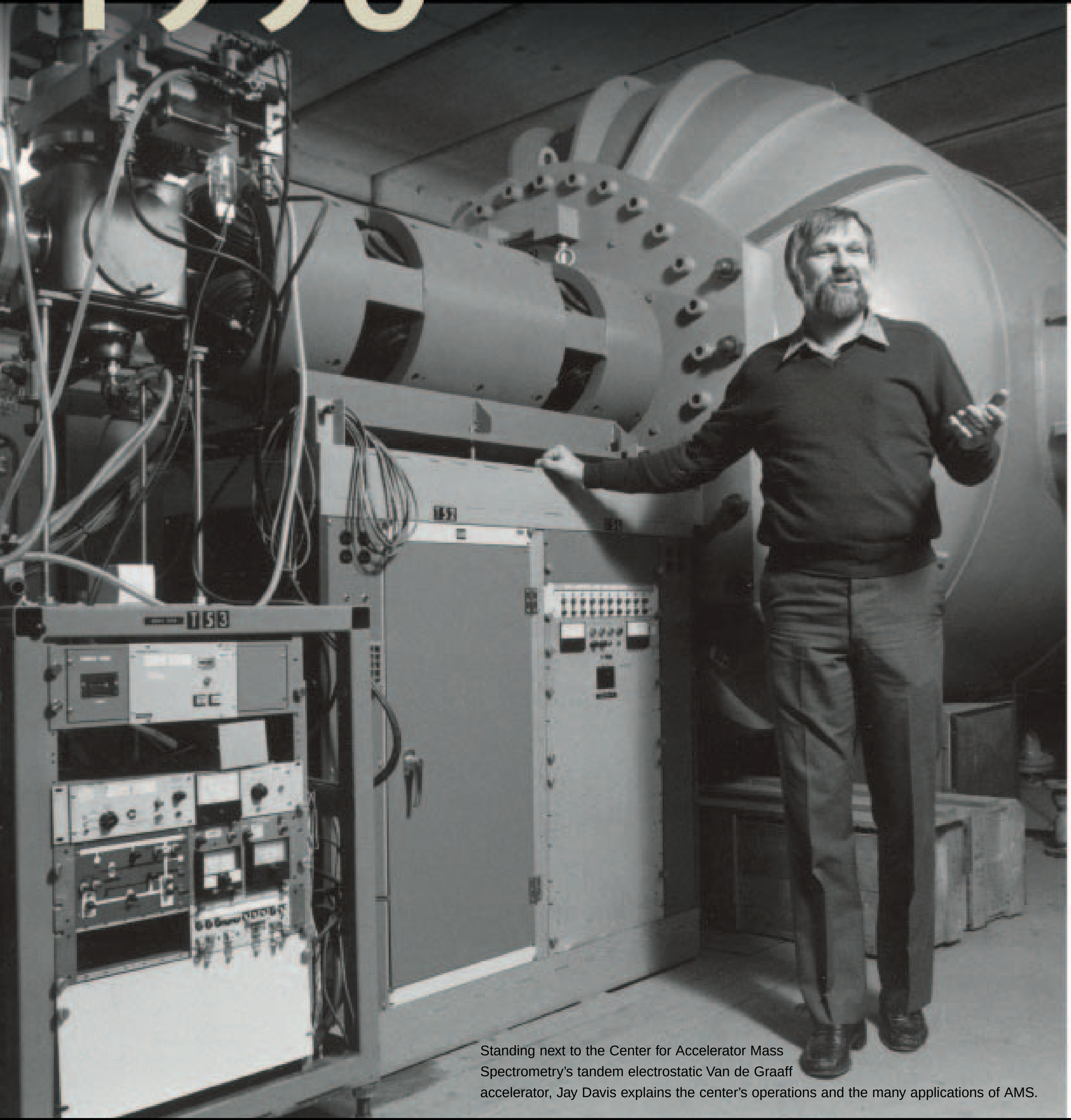
New Leadership

C. Bruce Tarter
(1994•2002)

A focus on national security

The Berlin Wall came down in 1989, the Cold War ended, and significant reductions were being made in strategic arsenals. Both the Soviet Union and the United States entered a nuclear testing moratorium in 1993 while recognizing an important continuing role for nuclear weapons in the post–Cold War world. The United States formally began its Stockpile Stewardship Program to maintain a safe, secure, and reliable nuclear deterrent in 1995. As a National Nuclear Security Administration laboratory, Livermore is a principal contributor to the program.

In the post–Cold War world, the Laboratory broadly contributes to the nation's science and technology base, but its defining mission remains national security. That mission is broader than stockpile stewardship. The invasion of Kuwait in 1990 and the subsequent discovery of aggressive Iraqi programs to develop weapons of mass destruction made clear that the world remained a dangerous place—complicated by the uncertain status of nuclear weapons and materials in a fragmented Soviet Union. Livermore responded by quickly expanding its analysis and technology-development program to prevent proliferation at its source, detect and reverse proliferant activities, and respond to the threat or use of weapons of mass destruction.



Standing next to the Center for Accelerator Mass Spectrometry's tandem electrostatic Van de Graaff accelerator, Jay Davis explains the center's operations and the many applications of AMS.

Detecting One in a Quadrillion

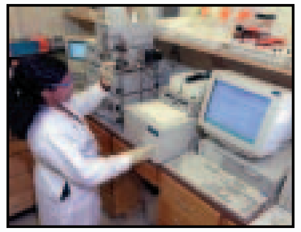
In 1990, soon after the Center for Accelerator Mass Spectrometry (CAMS) started operations, the first biomedical experiment using AMS was performed at Livermore. It measured the effects on rat DNA of a suspected carcinogen that results from cooking meat. From the beginning, CAMS was proving to be a highly versatile research facility, contributing to the success of a wide range of Laboratory programs and the research projects of many external users.

AMS is a sensitive technique for measuring concentrations of specific isotopes in very small samples—able to seek out, for example, one carbon-14 isotope out of a quadrillion (million billion) other carbon atoms. The technique enables Laboratory researchers to diagnose the fission products of atomic tests and monitor the spread of nuclear weapons to other countries by detecting radioisotopes in air, water, and soil samples. In addition, AMS supports studies in environmental quality, climate change, seismology, archaeology, biomedical science, and many other areas of scientific research.

The need for a multiuser AMS capability was recognized by Jay Davis, who at the time was a division leader, and he "sold shares" in the new accelerator facility to programs throughout the Laboratory, promising to get the facility built if they would help pay to run it. Additional support came in the form of one of Livermore's first large-scale initiatives in its Laboratory Directed Research and Development program. Davis also sold the idea to The Regents of the University of California (UC), winning funding from them in January 1987 to help support construction and continuing use of CAMS by UC faculty. To help lower costs, the designers used as many spare components as they could find. The accelerator came from the University of Washington, and a couple of the largest magnets had previous lives in an electron beam accelerator at Stanford University.

Established in 1988, CAMS was unique from the start because of the use of high-quality beam optics and a computer-control system that allows large numbers of high-precision measurements to be taken. The capabilities exceeded those of other AMS facilities because of the particularly demanding needs of the Laboratory's programs. An initial optimistic projection was that CAMS could someday handle 5,000 to 10,000 measurements in a year. Today, CAMS analyzes some 30,000 research samples annually—accounting for approximately one quarter of the worldwide AMS analyses performed per year. The center's scientists are participants in approximately 70 collaborative research projects with universities worldwide.

CAMS recently added a much smaller spectrometer that is dedicated to analyses of carbon-14 for biomedical and environmental research. In addition, the center operates a nuclear microprobe that has been used to develop pioneering applications in bioscience and environmental research. Since 1999, CAMS has been designated by the National Institutes of Health (NIH) as a National Research Resource for biomedical applications of AMS. It is midway through a five-year NIH grant that makes CAMS available to biomedical researchers around the world.



CAMS began operation in 1989 and now processes nearly 30,000 samples per year for its users (above). A recent addition to AMS capability at the Laboratory is a smaller spectrometer (not shown) dedicated to biomedical analyses.

Laboratory engineer Bill Nelson inspects the bombed-out reactor and nuclear research facilities at Tuwaitha (just outside Baghdad) during the first inspection after Desert Storm.

Inspecting for Weapons of Mass Destruction

At the end of Operation Desert Storm, the world was full of rumors about Iraq's nuclear capabilities and how much of them remained following an intense bombing campaign. In May 1991, a specially selected team, under the auspices of the United Nations Special Commission (UNSCOM) and the International Atomic Energy Agency (IAEA), was assembled for the first inspection of Iraqi nuclear facilities under UN Security Council Resolution 687. Laboratory engineer Bill Nelson was a member of that team.

The first and subsequent UNSCOM/IAEA inspections uncovered evidence of an advanced Iraqi nuclear program, code-named Petro-Chemical Project 3. At Tarmiya, inspectors uncovered Project 946, a uranium enrichment production facility that the Iraqis attempted to hide by removing railings from the floor of the building, pouring a new layer of concrete, and putting rubble on top. They had developed a first-class electromagnetic isotope separation capability, with supporting research and industrial infrastructure. Production of 10 to 30 kilograms of highly enriched uranium, a key component of nuclear weapons, might have occurred within two years.

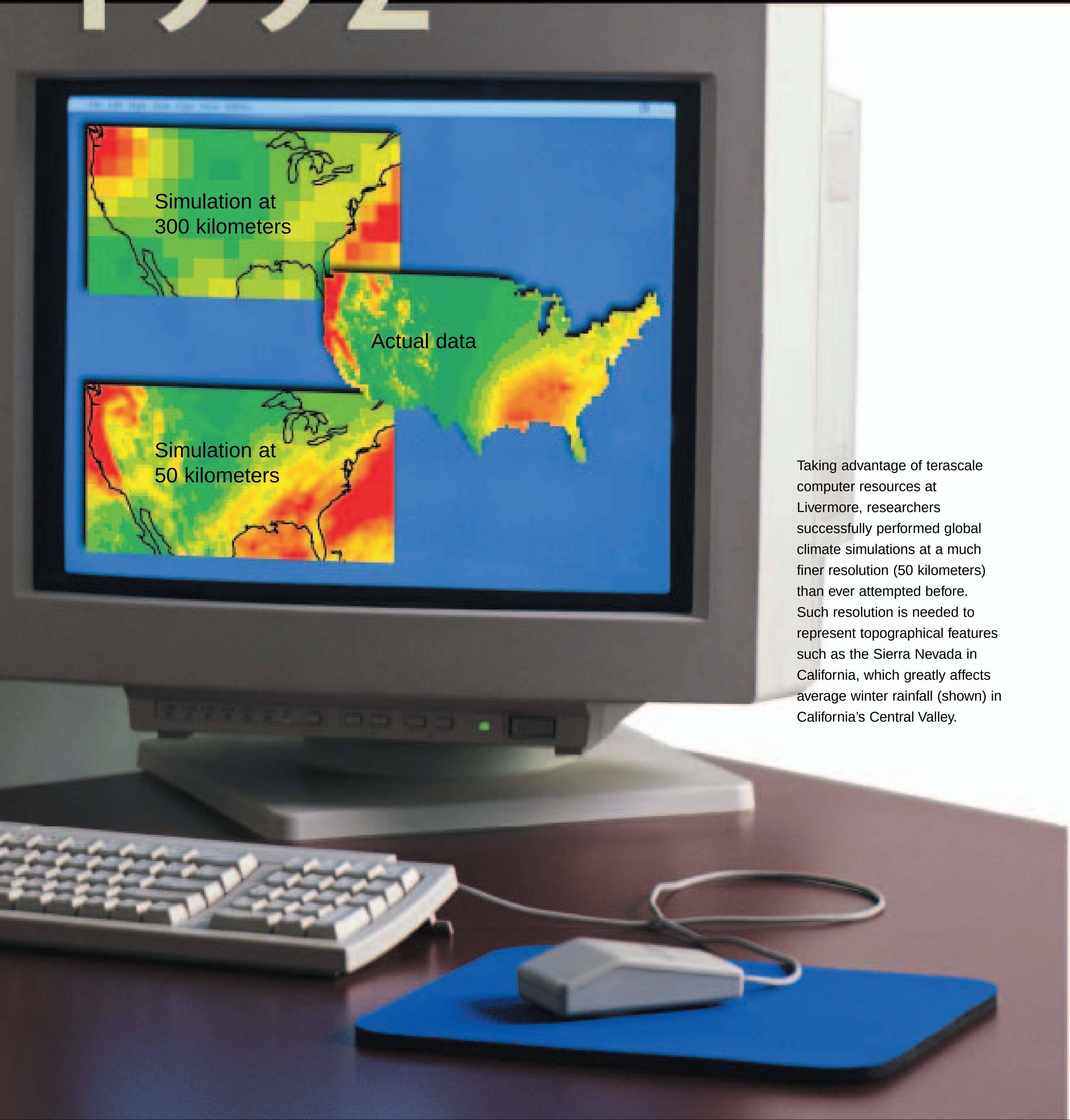
Perhaps the defining moment came in September 1991, when UNSCOM/IAEA Team 6 discovered a large cache of documents. Two Laboratory scientists were on the team; another was at the UN supporting the operation. For five days, there was a standoff in Baghdad between the team of inspectors, which wanted to remove the documents from where they were found, and hundreds of heavily armed Iraqi soldiers. Sleeping on pieces of cardboard in the building's parking lot and sometimes without even water, the group refused to leave without the papers they considered to be the smoking gun. The documents indeed proved critical in establishing a knowledge baseline of the Iraqi program.

Iraqi facilities were inspected for any evidence of weapons of mass destruction—not just nuclear, but also chemical and biological weapons and ballistic missiles—and equipment was destroyed, seized, or subjected to monitoring. In all, over a dozen Laboratory researchers took part in various inspections until the UN removed all personnel in 1998 because of an increasingly hostile atmosphere. Livermore scientists also developed, installed, and maintained sophisticated inspection and monitoring equipment in Iraq, such as automated cameras and microwave communication links for remote surveillance of facilities that could be used in missile production.

Livermore continues to provide technology, analysis, and expertise to help prevent the spread or use of weapons of mass destruction. Soon after the Iraq inspections began, Laboratory Director John Nuckolls formed the Nonproliferation, Arms Control, and International Security (NAI) Directorate. The new directorate merged a variety of related activities into a comprehensive program to address all steps in the nonproliferation process, including prevention, detection and reversal, and response to potential proliferant states and terrorists.

Iraqi Calutrons

Laboratory physicist Jay Davis, twice a member of UNSCOM/IAEA inspection teams, found the Iraqi isotope separation technology was similar to that developed at the University of California (UC) at Berkeley in the late 1940s to enrich uranium for America's first atom bomb. Called the calutron because of its UC origin, the technology was abandoned by the U.S. because of cost. However, it was an excellent choice for Iraq in that calutrons required few outside resources. Davis estimated the Iraqi Manhattan Project–style effort at between 6 billion dollars and 8 billion dollars and noted that the quality of work was "every bit as good as we could do today."



Taking advantage of terascale computer resources at Livermore, researchers successfully performed global climate simulations at a much finer resolution (50 kilometers) than ever attempted before. Such resolution is needed to represent topographical features such as the Sierra Nevada in California, which greatly affects average winter rainfall (shown) in California's Central Valley.

Better Global Climate Models and Analysis

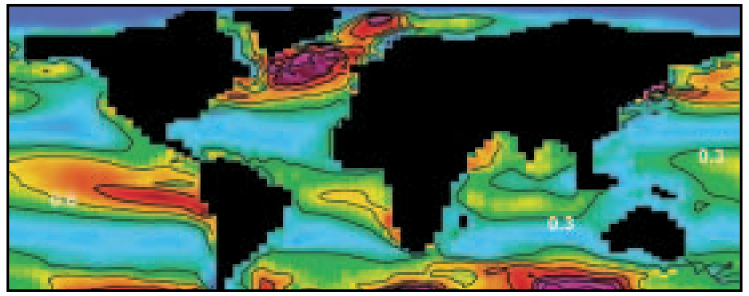
In 1992, Laboratory atmospheric scientist Larry Gates issued *The Validation of Atmospheric Models*, the first of a continuing series of reports that would radically alter global climate change research and the way models characterize climate. The report came five years after Gates, an atmospheric science professor at Oregon State University, had come to the Laboratory on a sabbatical. One year later, Gates and fellow atmospheric scientists formed a new group at the Laboratory—the Program for Climate Model Diagnosis and Intercomparison (PCMDI).

PCMDI quickly became an internationally recognized institution for climate model analysis. The program integrates the talents of physical (atmospheric) scientists and computer scientists, following the approach of other interdisciplinary programs at Livermore. PCMDI's mission is not to make new models but rather to set a standard by which all climate models adhere so as to lend validity to the models themselves. The ultimate goals are to develop improved methods and tools for the diagnosis, validation, and intercomparison of global climate models and to conduct research on a variety of problems in climate modeling and analysis. PCMDI's software system is recognized around the world for its efficiency and flexibility.

The need for standards in both modeling and analysis has become increasingly apparent as more complex models are developed. The disagreements among models and between models and observations remain significant and poorly understood. The nature and causes of these conflicts must be accounted for in a systematic fashion before models can be confidently used for climate prediction studies in support of global change research.

PCMDI's work goes beyond the nation's borders. The group is coordinating the Atmospheric Model Intercomparison Project (AMIP) on behalf of the Working Group on Numerical Experimentation of the World Climate Research Programme. In this project, some 30 international modeling groups are simulating the climate of the decade 1979–1988, and PCMDI is evaluating the results. In addition, PCMDI has extensively studied the effects of resolution on climate simulations performed with the European Centre for Medium-Range Weather Forecasts' atmospheric model.

Atmospheric scientists at PCMDI have also been key participants in international efforts examining the evidence for climate change due to human activities. Ben Santer, who received the prestigious MacArthur Foundation "genius award" in 1998, served as lead author for Chapter 8 ("Detection of Climate Change, and Attribution of Causes") of the *1995 Second Assessment Report of the Intergovernmental Panel on Climate Change*. The report concluded that "the balance of evidence suggests a discernible human influence on global climate." In addition, Santer and Karl Taylor have received awards for their work on global warming from the World Meteorological Organization.



Ocean circulation models are used to study northerly movement of the carbon dioxide soaked up by cold water in the Southern Ocean. Efforts are under way to develop an integrated climate and carbon-cycle model.

In the late 1950s, Laboratory physicist Cecil "Chuck" Leith and his group applied numerical methods used for weapon physics to develop the first global general circulation model, able to simulate the behavior of large weather systems. Results were displayed in a movie (left) of the model's weather on a map centered at the North Pole.

1993 Dynamic Underground Stripping

Dynamic underground stripping cleans up underground hydrocarbon spills. The method is used in combination with other Livermore-developed monitoring and remediation technologies to rapidly remove contaminants from groundwater or destroy them in place.

Hot Technology Removes Contamination

If the Laboratory had used conventional methods in 1993 to clean major leaks from its underground gasoline tanks, the project would still be under way. Estimates had pegged the time at 30 to 60 years to remove thousands of gallons of gasoline that had leaked into the soil beneath the shipping and receiving area north of East Avenue. But instead of decades or even years, the 7,600 gallons of gasoline were mopped up in about four months using remediation technologies developed by Laboratory scientists Roger Aines, Robin Newmark, and John Ziagos in collaboration with a University of California at Berkeley researcher.

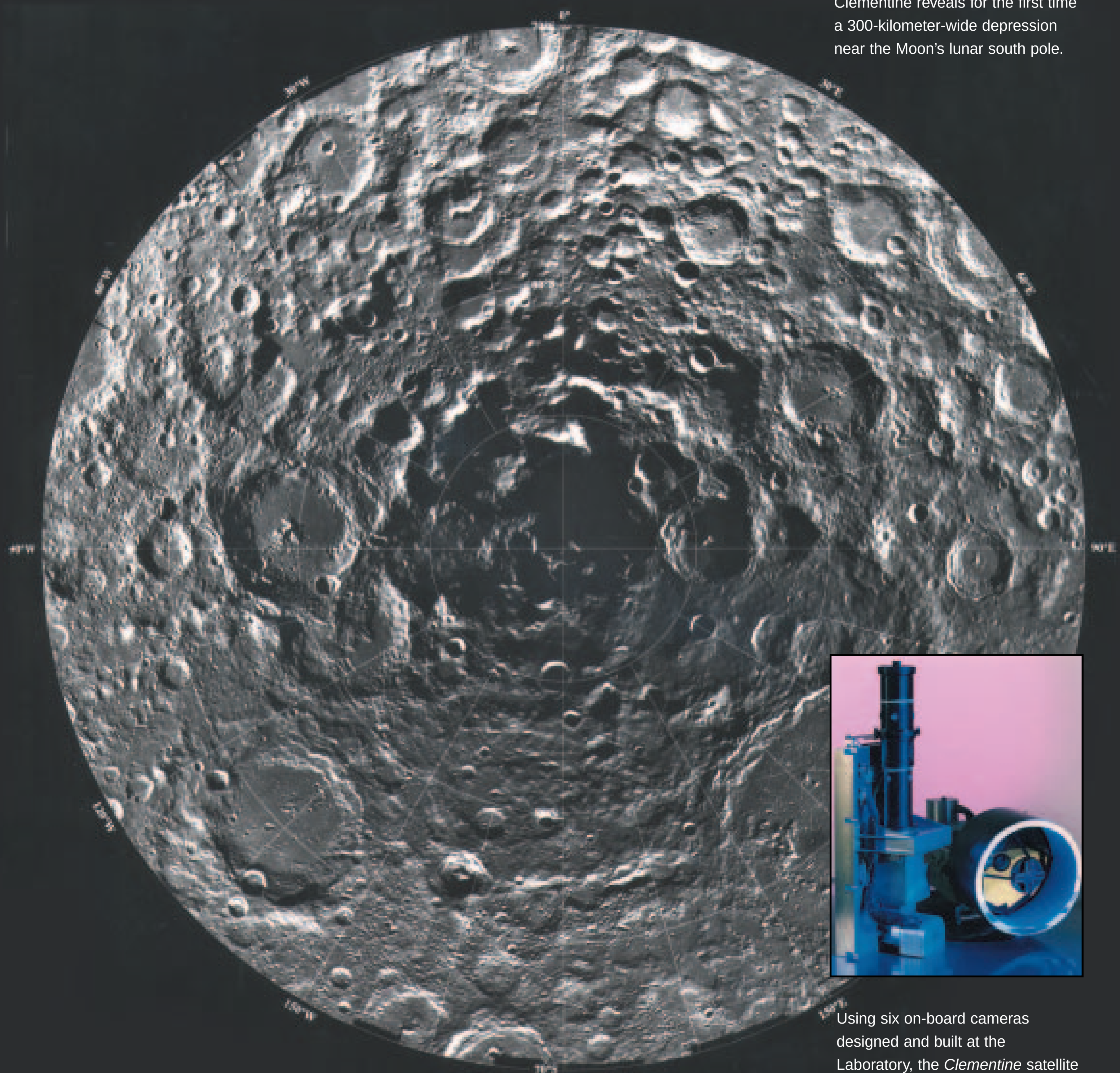
The technique, called dynamic underground stripping, involves injecting steam to heat the ground. Contaminants are vaporized and driven to extraction wells, where they are easily removed from soil and water. The heat and forced air chemically break down many contaminants in place, leaving harmless compounds. Electric currents heat soils that are too impermeable for steam to penetrate. The treatment of contaminants is even more effective when dynamic underground stripping is combined with two related remediation technologies subsequently pioneered by Livermore researchers: electrical resistance tomography, for monitoring an underground clean-up in real time; and hydrous pyrolysis/oxidation, which destroys pollutants where they are found underground.

Department of Energy officials have estimated that the Livermore-developed environmental technology has the potential to remediate up to one-quarter of the nation's 1,300 Superfund sites. Already, the technology has achieved remarkable success cleaning a Superfund site in Visalia, California, between 1997 and 1999. For nearly 60 years up to 1980, Southern California Edison had treated utility power poles with carcinogenic wood preservatives such as creosote and pentachlorophenol, some of which leaked into the ground. Using older clean-up methods at Visalia, about 275 pounds of contaminants had been removed in one nine-month period. However, with the use of the Livermore technology, Southern California Edison, working with the Laboratory and a licensee, was able in a similar nine-month period to pull about 540,000 pounds of pollutants—almost 2,000 times more. During the entire three-year Visalia clean-up, about 1.2 million pounds of contaminants were removed from the four-acre site using the dynamic underground stripping technology. Now many sites that were considered uncleanable like Visalia are being considered for the steam approach.

To date, three California companies—SteamTech Environmental Services of Bakersfield, Southern California Edison of Rosemead, and Integrated Water Resources, Inc. of Santa Barbara—have licensed the Livermore environmental technologies. Beyond the Visalia clean-up project, these three companies have or will be using the dynamic underground stripping technologies to clean nine U.S. sites contaminated with difficult underground pollutants. The sites include Cape Canaveral, DOE's Savannah River Site and Pinellas Plant, and Beale Air Force Base.

Two complementary technologies pioneered at Livermore are successfully cleaning up contaminated groundwater and soil at facilities in several states. Hydrous pyrolysis/oxidation combined with dynamic underground stripping are destroying contaminants in situ as well as bringing them to the surface at 5,000 times the rate of other technologies.

1994 Clementine



A mosaic of 1,500 images taken by Clementine reveals for the first time a 300-kilometer-wide depression near the Moon's lunar south pole.

Using six on-board cameras designed and built at the Laboratory, the *Clementine* satellite mapped the entire surface of the Moon in 1994 at resolutions never before attained.

Advanced Sensors Map the Moon

The Clementine Deep Space Experiment, sponsored by the Ballistic Missile Defense Organization, was launched on January 25, 1994—22 months after the effort began. At a mission cost of less than $100 million, it was the first U.S. spacecraft to visit the moon in over two decades. The Clementine mission collected over 1.7 million images during its two months in lunar polar orbit. The data has enabled global mapping of lunar-crust rock types and the first detailed investigation of the geology of the lunar polar regions and the lunar far side.

The *Clementine* spacecraft included new advanced technology sensors and space component technologies that provide the basis for a next generation of lightweight satellites for civilian and military missions. It incorporated 23 advanced subsystem technologies and had a dry mass of only 500 pounds. The spacecraft's payload consisted of an advanced sensor suite weighing less than 16 pounds that was designed, fabricated, integrated, and calibrated by Laboratory scientists and engineers with the support of industrial contractors. The Naval Research Laboratory designed, integrated, and operated the spacecraft. NASA provided mission design and operational support.

Clementine carried an ultraviolet-visible camera, a shortwave infrared sensor, a longwave infrared sensor, an imaging lidar (light detection and ranging) instrument, and two Star Tracker cameras. These instruments successfully mapped the entire lunar surface in 11 spectral bands. By laser ranging, the lidar system also generated a global topographical data set. The topography of the moon's many ancient impact basins was measured, and a global map of the thickness of the lunar crust was derived. In addition, bistatic radar measurements made over the Deep South polar depression indicated the presence of frozen water on the moon.

Sensor system technologies were derived from Livermore's space-based interceptor development program. The Strategic Defense Initiative Organization (SDIO) funded related research beginning in 1985, and in November 1987, the Brilliant Pebbles effort formally commenced. The concept was to deploy a constellation of sophisticated, inexpensive, lightweight spacecraft in low Earth orbit—Brilliant Pebbles—that could detect and hunt down missiles over distances of thousands of kilometers without external aid. In the summer of 1989, Brilliant Pebbles was adopted by SDIO as the new baseline for the space-based segment of a national missile defense system.

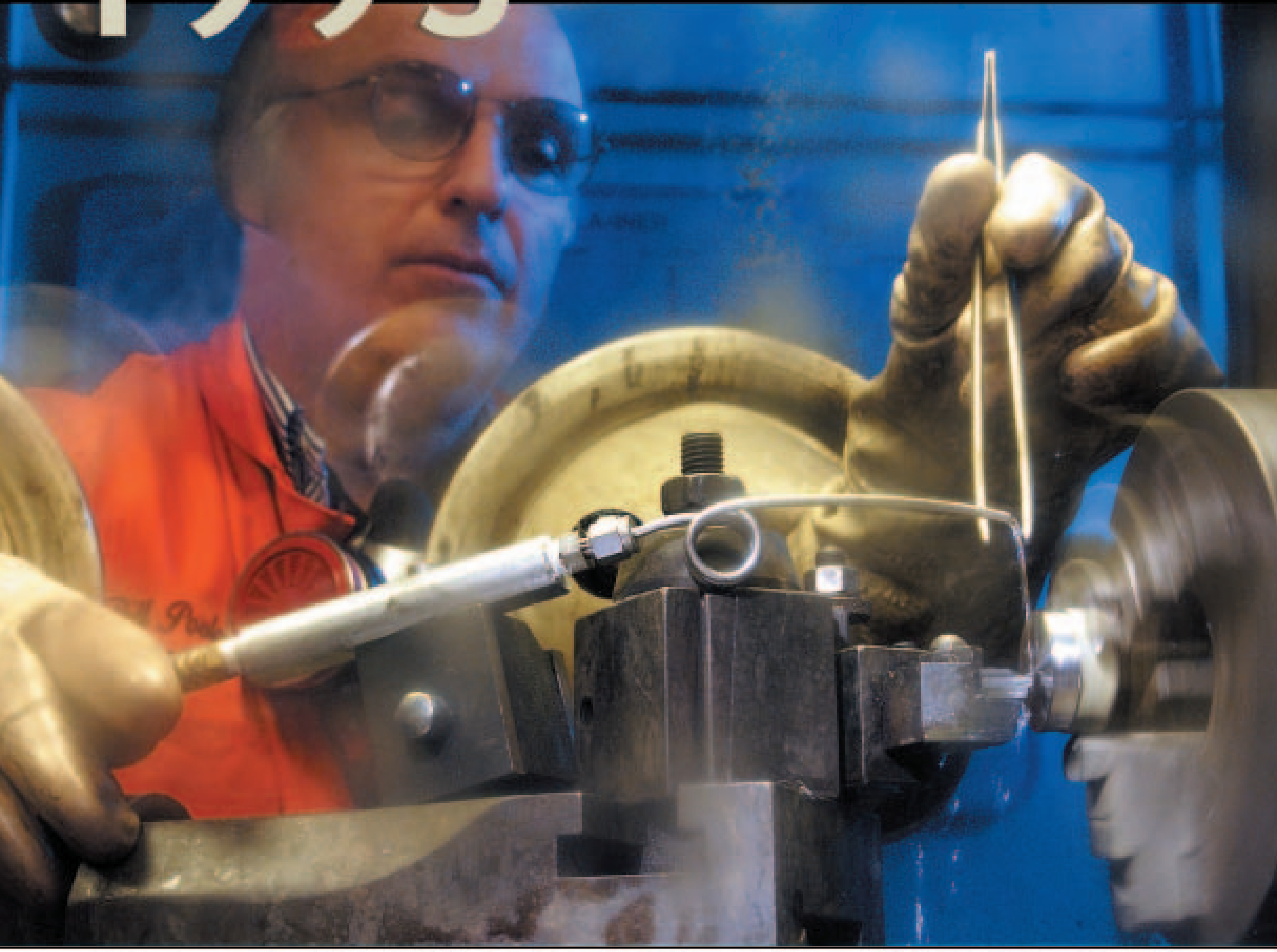
A wide variety of projects to develop state-of-the-art sensor technologies at the Laboratory are building on the success of the Clementine program. One example is the development of a large-format digital camera system that uses charge-coupled device detectors. The 16-million-pixel cameras have been used by astronomers in the search for massive compact halo objects (MACHOs), a form of dark matter.

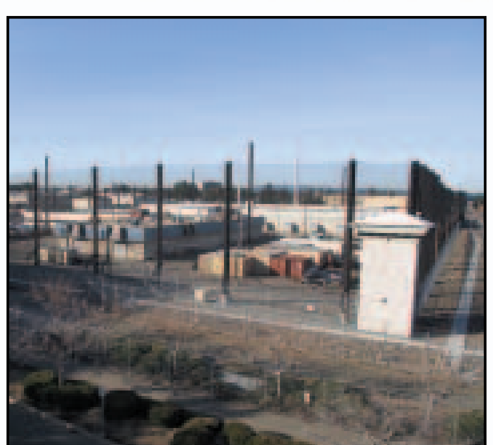
O Group

Under the leadership of physicist Lowell Wood, O Group pursued a variety of imaginative research projects in the late-1970s and the 1980s. O Group included many extremely talented young scientists, some of who came to the Laboratory as Hertz Foundation fellows. An exceedingly ambitious early project was the design of the S-1 supercomputer, an effort which led to the development of computerized design methods, including Structured Computer-Aided Logic Design (SCALD), that successfully spun-off from the Laboratory. O Group pioneered the development of x-ray lasers and gave birth to the concept of Brilliant Pebbles.

Lowell Wood presented President George Bush with a conceptual model of Brilliant Pebbles when the President visited the Laboratory in 1990.

1995 Stockpile Stewardship





The Livermore Superblock (far left) is home to one of only two defense plutonium research and development facilities in the U.S. For the nation's Stockpile Stewardship Program, trained fissile material handlers prepare samples for nonnuclear tests (left), conduct experiments to study the properties of plutonium, and examine parts of selected weapons from the stockpile for signs of aging (above).

Understanding the Details of Nuclear Weapon Performance

In 1995, the Stockpile Stewardship Program formally began when President Clinton reached two critical decisions that established the course for future nuclear-weapons activities in the United States. At the time, both the U.S. and Russia were reducing the size of their nuclear arsenals, both nations had been observing a moratorium on nuclear testing for three years, and the U.S. had halted its programs to develop new nuclear weapons.

First, on August 11, 1995, the President announced that the U.S. would pursue a Comprehensive Nuclear Test Ban Treaty. In making that decision, he also reaffirmed the importance of maintaining a safe and reliable nuclear weapons stockpile. Then, on September 25, 1995, the President directed necessary programmatic activities to ensure continued stockpile performance. Under the leadership of Vic Reis, the Department of Energy's Assistant Secretary for Defense Programs, DOE national security laboratories and the weapons production facilities worked with DOE Defense Programs and the Department of Defense to formulate the Stockpile Stewardship Program.

The program was launched as an ambitious effort—not without risks—to significantly improve the science and technology base for making informed decisions about an aging nuclear weapons stockpile without relying on nuclear testing. All aspects of weapons must be understood in sufficient detail so that weapons experts can assess the performance of the nation's nuclear weapons with confidence and make informed decisions about refurbishment, remanufacture, or replacement of weapons as needs arise.

To succeed, the three DOE national security laboratories, now part of the National Nuclear Security Administration, needed much more advanced experimental and computational capabilities. At Livermore, the National Ignition Facility is under construction (see Year 1997), and new supercomputers are being acquired as part of the Advanced Simulation and Computing (ASCI) program (see Year 2000). As new capabilities are coming on line, they are contributing to surveillance of stockpiled weapons to determine their condition, assessment of weapon safety and reliability, activities to extend the lifetime of weapons, and certification of refurbished warhead systems. The new experimental and computational capabilities also are being used to train and evaluate the skills of the next generation of stockpile stewards, who depend on these tools to help maintain the nuclear stockpile.

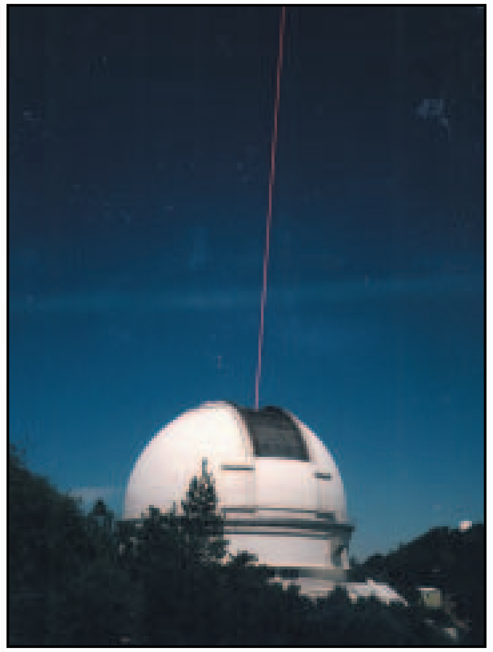
To date, the Stockpile Stewardship Program is making excellent technical progress. For example, researchers are dramatically improving their understanding of the properties and aging of materials in weapons, and the sophistication and resolution of three-dimensional simulations of weapon performance are rapidly increasing. In addition, Livermore has successfully completed engineering development work on its first stockpile life-extension program (see Year 1986). However, many of the toughest challenges probably lie ahead as weapons continue to age. The long-term success of stockpile stewardship depends on a continuing strong national support for the program and on the skills and capabilities of future generations of weapons experts at the nuclear weapon laboratories.

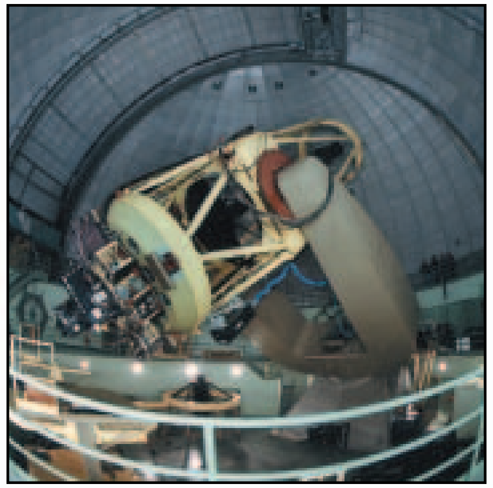
Expansion of Livermore's computing power requires construction of the $92-million Terascale Simulation Facility (TSF), which began in April 2002 with a groundbreaking ceremony. The TSF is designed to accommodate a 60- to 100-teraops machine (ASCI Purple) that will move scientists closer to the goal of performing full-scale simulations of weapon performance based on first-principles physics. The TSF will also house a growing support staff and researchers who work on projects such as developing new tools to assimilate the vast amount of data generated.

Photo credit: John McDonald/Canada-France-Hawaii Telescope Corp.

Heralding a New Era in Astronomy

The Shane telescope's Livermore-developed adaptive optics subsystem (below and bottom) was the first such laser system on a major astronomical telescope. Adaptive optics were installed in the Keck telescope (left) in 1998, and in 2001, a laser guide star system was added.





In September 1996, observers at University of California's Lick Observatory, atop Mount Hamilton near San Jose, California, obtained their first image that was significantly improved through use of a laser guide star and adaptive optics. The event heralded a new era in astronomy. Atmospheric distortions, which cause stars to twinkle and have haunted astronomers since Galileo, no longer need limit the performance of Earth-based telescopes.

Two years earlier, a Livermore-designed adaptive optics system was installed on Lick's 3-meter Shane telescope. To correct for atmospheric turbulence, an adaptive optics system uses a large number of computer-controlled actuators to precisely adjust the shape of a deformable mirror up to several hundred times per second. The technology has benefited from the efforts of many researchers, including the team at Livermore, which developed adaptive optics for use as part of the Atomic Vapor Laser Isotope Separation (AVLIS) program (see Year 1973). Adaptive optics are also central to the design of the lasers for the National Ignition Facility (see Year 1997).

The adaptive optics system alone benefits astronomers only if the object being studied has a sufficiently bright nearby star that can be used to determine the atmospheric distortions that must be corrected. In most cases, there is no such star, and one has to be created—a "laser guide star." The team of Laboratory and University of California researchers working on the Lick project, led by Livermore's Claire Max, installed a laser guide star system at Lick in 1996. A 15-watt dye laser system, a technology developed as part of the AVLIS program, was retrofitted onto the Shane telescope. Light from the laser reflects off a layer of sodium atoms in the upper atmosphere (about 100 kilometers altitude), creating the needed artificial star.

Subsequently, a team from Livermore, the University of California, and the California Institute of Technology installed adaptive optics and a laser guide star system on the 10-meter telescope at Keck Observatory in Hawaii. Since first observations in 1998, the adaptive optics have enabled astronomers to obtain infrared-light images of unprecedented resolution—four times better resolution than the Hubble Telescope's. For example, astronomers using the Keck telescopes have obtained the best pictures yet of Neptune. The images reveal a wealth of information about small-scale features in Neptune's atmosphere and suggest violent methane storms with wind speeds reaching more than 1,700 kilometers per hour.

In December 2001, "first light" was achieved with a newly installed laser guide star system for Keck. When the laser guide star is fully integrated with adaptive optics systems in 2002, new frontiers of research and new kinds of observations—perhaps including images of a planet orbiting a distant star—will become possible.

Astrophysics at Livermore

Because astrophysics and nuclear weapons physics have many similarities, it is not surprising that the Laboratory has a long history of contributing to the advancement of scientific understanding about our universe and developing instrumentation used by astronomers. Pioneering work in the 1960s includes seminal papers on gravitational collapse and supernova explosions by Laboratory researchers including Sterling Colgate, Montgomery Johnson, Michael May, Richard White, and James Wilson. Current efforts range from laser guide star development and use to the search for dark matter (massive compact halo objects, or MACHOs) and the development of a three-dimensional stellar evolution simulation model.

The 192-beam National Ignition Facility during construction in 2001 (top). The 10-meter-diameter target chamber (above and right) was moved into the facility in 1999.

Thermonuclear Ignition and Matter at Extreme Conditions

Groundbreaking for the stadium-sized 192-beam National Ignition Facility (NIF) took place in May 1997. An extremely ambitious and technically challenging project, NIF is the culmination of a series of increasingly larger lasers built over the past 30 years. It will be the world's most energetic laser when completed. With NIF, scientists will perform vitally needed thermonuclear weapons physics experiments. The facility is a cornerstone in the U.S. nuclear weapons Stockpile Stewardship Program to ensure the safety and reliability of the nuclear deterrent. NIF also will serve as a national and international center for the study of inertial confinement fusion (ICF) and the physics of matter under conditions of extreme temperature, energy density, and pressure.

NIF is designed to deliver 192 laser beams with a total energy of 1.8 million joules of ultraviolet light to the center of a 10-meter-diameter target chamber. This energy, when focused into a volume less than a cubic millimeter, can provide unprecedented energy densities in a laboratory setting. In ICF experiments, NIF's laser beams will converge on a target containing a BB-size capsule of deuterium–tritium fuel causing the capsule to implode and create fusion ignition and burn with the release of approximately 10 times more energy than was used to drive the implosion. Additionally, scientists will use NIF to study a variety of materials under high-energy-density conditions to provide valuable data for national security, energy security, basic science, and nuclear weapons effects.

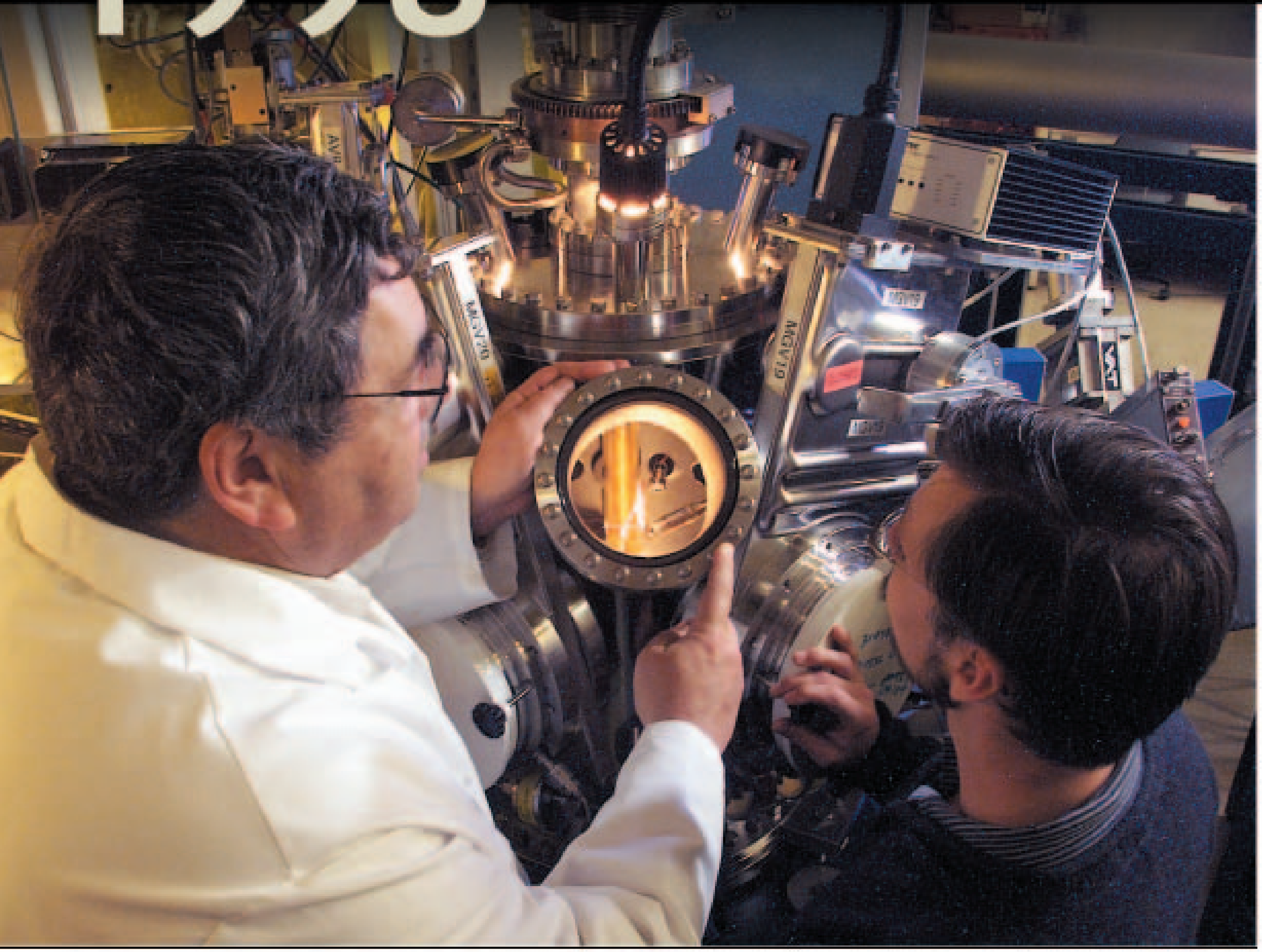
In June 1999, after two years of construction, the 132-ton aluminum target chamber was transported from its assembly building to the target bay where it is now aligned to better than a millimeter accuracy. While excellent progress was being made on all technical fronts and construction continued on the $270-million conventional facility, the NIF project was rebaselined to enhance the planned method for assembling the lasers and to ensure that strict cleanliness requirements would be met.

In September 2001, conventional facility construction was completed on schedule and on budget. Inside the building, the beampath infrastructure for the first 48 beams was completed the next month. This significant milestone was accomplished through the successful partnership of the installation contractor, Jacobs Facilities, Inc., Laboratory staff, and the local building trades. In early 2002, assembly work stations were commissioned in the Optics Assembly Building, where over 7,000 large-aperture and over 10,000 smaller optical components required by NIF will be received, cleaned, assembled, aligned, and transported to the laser.

The NIF schedule calls for project completion in FY 2008, and the NIF team's goal in the coming year is to achieve "first light" by delivering four laser beams to the target chamber.

Target Chamber Construction

The 10-meter-diameter target chamber was assembled from 18 four-inch-thick aluminum sections fabricated by Pitt-Des Moines, Inc., of Pittsburgh, Pennsylvania, in a special-purpose building adjacent to the National Ignition Facility. After verifying that the vessel was leak-free in June 1999, the 132-ton vessel was hoisted by one of the largest cranes in the world and carefully installed onto its support pedestal in the target building. Surprisingly, this breathtaking event took only about 30 minutes. The seven-story walls and roof of the target bay were then completed, and the target chamber was coated with a special 16-inch-thick neutron shielding concrete shell. Now weighing about 1 million pounds, the complete target chamber has been precision aligned to better than 1-millimeter accuracy.



Livermore materials simulations are closely coupled to a program of laboratory experiments. Researchers measure the atomic transport properties of radiation damage defects in metals, including plutonium. The data are used to refine codes that simulate and predict the performance of stockpiled nuclear weapons.

Material Properties from Atomic to Large Scales

For years, scientists have longed for computer simulations that could accurately predict material performance from atomic to engineering scale. In 1998, researchers at the Laboratory made great strides toward this goal, developing experimentally verified, three-dimensional simulations that bridge these extreme scales. The first simulations focused on the mechanical behavior of molybdenum, using information generated at the atomic scale (measured in nanometers) to model phenomena occurring at the microscale (micrometers). The results of these microscale simulations—the strength properties of molybdenum—were then passed on to codes that model phenomena on longer scales. Researchers validated their codes by comparing their simulations to experimental results. Ultimately, the validated codes will be used to predict changes in properties in other materials of particular interest to Laboratory programs.

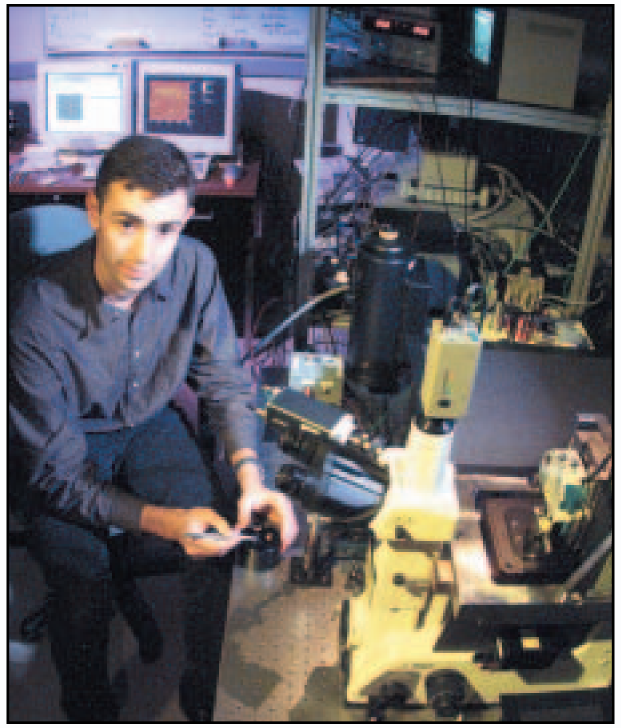
The multiscale modeling approach only became possible with the advent of powerful, multiprocessor supercomputers in the last decade. Using the massively parallel computers of the National Nuclear Security Administration's Advanced Simulation and Computing (ASCI) program (see Year 2000), Livermore's researchers can now model material behavior over length scales ranging from nanometers to meters and time scales ranging from billionths of a second to tens of years.

Through multiscale modeling and experiments, scientists are gaining a better understanding of the effects of radiation damage on materials. The issue is of particular importance to scientists in the Stockpile Stewardship Program who are concerned about the aging of materials in nuclear weapons. In 2000, a Livermore team headed by materials physicist Tomas Diaz de la Rubia used multiscale modeling and experiments to demonstrate for the first time the underlying connection between radiation damage (in crystalline metals), which occurs at ultrasmall scales (nanometers and picoseconds), to degradation over time of the material's mechanical properties.

Many other research activities at the Laboratory are also benefiting from the work. At the National Ignition Facility (NIF), scientists are applying experimentally verified multiscale modeling to predict the lifetime of optics subjected to NIF's high-intensity laser light. The multiscale approach is also being used to model materials that could be used in future fusion reactors and to model the long-term performance of canisters being considered for storing high-level nuclear waste at Yucca Mountain (see Year 1980). In the future, multiscale modeling may provide insights into the manufacturing processes used in the semiconductor industry and simulate biochemical processes to aid in the study of DNA.

Delving into Radiation Damage

Inherently a multiscale phenomenon, radiation damage can occur over a scale of 100 nanometers and in a small fraction of a second, but the effects build up over decades. Radiation damage can produce unacceptable changes in the plutonium used in nuclear weapons, shorten the lifetime of pressure vessels in nuclear power plants, and limit the choice of materials for fusion energy research. Livermore's scientists have a long-standing interest in the topic; the Livermore Pool-Type Reactor, which operated on site from 1957 to 1980, provided neutrons to study radiation damage to materials.



Livermore scientists are examining how materials are organized on surfaces and are conducting their examinations on an atom-by-atom and molecule-by-molecule basis. At this nanometer scale, scientists must use only the most powerful imaging tools, such as the extremely high-resolution atomic force microscope.

1999 R&D 100 Awards

The Ultra Clean Ion Beam Sputter Deposition System, developed at Livermore, produces precise, uniform, highly reflective masks in the lithographic process of printing features on computer chips. In a collaboration of national laboratories and industry, Livermore supplies expertise in optics, precision engineering, and multilayer coatings.

Technologies Spin Off to Industry

In 1999, *R&D Magazine* recognized Livermore with 6 of the 100 awards it grants annually for the most technologically significant new products and processes. The magazine, a publication for scientists and engineers, has been holding the R&D 100 Awards competition since 1963 to recognize important technological advancements that can be commercialized and that promise to improve people's lives. Over the years, Livermore has won 90 of these coveted awards. That large number is a credit to the outstanding science and engineering work at the Laboratory as well as to Livermore's excellent track record in working with industry.

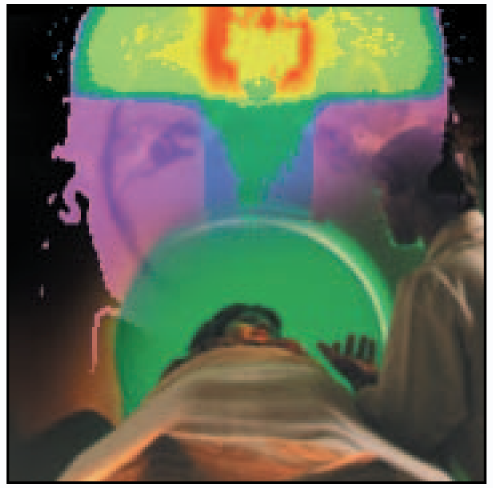
Two of the 1999 awards are indicative of the Laboratory's wide variety of partnerships with U.S. industry and how technologies developed for national security applications often lead to broader societal benefits. One award was for PEREGRINE, a revolutionary new tool for helping doctors to plan radiation treatment on a patient-specific basis. Its modeling explicitly accounts for inhomogeneities in the body such as air, muscle, and bone that are identified on the patient's computed-tomography scan. The power and accuracy of PEREGRINE are based on Livermore's storehouse of data on nuclear science and radiation transport combined with Monte Carlo statistical techniques.

Livermore licensed the PEREGRINE technology to the NOMOS Corporation of Sewickley, Pennsylvania, in 1999. The U.S. Food and Drug Administration approved it for use in 2000.

Another R&D 100 Award in 1999 was for a multilayer, thinfilm deposition system, a technology that is key to the development of extreme ultraviolet (EUV) lithography. EUV lithography promises to allow computer chip manufacturers to print circuit lines at least as narrow as 0.03 micrometer (1/3,000th the width of a human hair), which will extend the current pace of semiconductor innovation at least through the end of the decade.

The technology is being pursued by a unique industry–government collaboration that began in 1997. It involves the Lawrence Livermore, Lawrence Berkeley, and Sandia national laboratories and a consortium of semiconductor companies called the EUV Limited Liability Company (LLC). The consortium, which has committed $250 million to the project, includes Intel, Motorola, Advanced Micro Devices, Micron Technology, Infineon Technologies, and IBM. In October 2001, EUV LLC extended the cooperative research and development agreement to 2005.

Drawing on optical technology and precision engineering that supports its laser programs, the Laboratory brings to the project expertise in creating precision reflective optical coatings from multilayered materials, advanced optical testing methods, and defect inspection technologies. In the future, Livermore will directly benefit from the more powerful computers that will be made possible by EUV lithography.



Winner of an R&D 100 Award in 1999, PEREGRINE (top left) helps doctors to better plan radiation treatment. The computer simulation of the dose received uses detailed, patient-specific information gathered through a computed-tomography scan. The Laboratory has won a total of 90 R&D 100 Awards (bottom left).